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A review of blade structures of SWTSs in the Aegean region and performance analysis

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Abstract

Wind energy applications have rapidly increased in the world, so the efficiency of wind energy constructions is gaining importance. Using small wind turbines, farmers, ranchers, and homeowners can reduce their utility bills, stabilize their electricity supplies, and contribute to the nation's energy supply, and thus play an important role in securing our energy future. Distributed wind electric systems represent an opportunity for some nations in particular. This study aims (i) to investigate the efficiency differences between three bladed glass reinforced plastics (GRP) rigid hubs, three bladed steel rigid hubs and twelve bladed steel rigid hubs experimentally, and (ii) to improve the performance of the small wind turbine system (SWTSs) installed at the Solar Energy Institute of Ege University (latitude 38.24° N, longitude 27.50° E), Izmir, Turkey. NACA 4415 (National Advisory Committee for Aeronautics) series blades are preferred to others in this experiment, because of the fact that this profile has shown excellent properties for small wind turbine blades and their average power coefficients are higher than those of other blades. In this study, the performance parameters of the SWTSs are given first. An experimental study is then presented. Finally, the results obtained from the present study are discussed.

Keywords: Wind; Wind energy; Renewable energy; Turkey; Windmills; Small wind turbines; Environment

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Contents

Nomenclature

A	rotor swept area (m^2)
C_L	aerodynamic lift coefficient (–)
C_D	aerodynamic drag coefficient (–)
C_M	momentum factor of rotor (–)
C_P	power coefficient (energy conversion ratio) (–)
I	current (A)
R	maximum rotor radius (m)
V_r	local wind velocity (m/s)
V	voltage (V)
P	available power (W)
P_a	actual SWTS power (active power at generator output) (W, kW)
$\dot{m}$	mass flow rate of air (kg/s)
n	spin number (number of revolutions) of generator rotor per minute (rpm)
ω	angular velocity of rotor (rad/s)
η	efficiency (–)
Δt_i	yearly cumulative time (h/year)
λ	tip speed ratio (–)
ρ	air density (kg/m^3)
GRP	glass fiber reinforced plastics
NACA	National Advisory Committee of Aeronautics
SWTS	small wind turbine system (windmill)

1. Introduction

Wind energy was first used more than 3500 years ago in boats to transport goods, in Egypt, or to grind seeds to produce flour, and has some key advantages, such as cleanliness, abundance in most parts of the world, low cost, sustainability, safety, popularity, and effectiveness in creating jobs. Ample attention is now directed toward the use of renewable wind energy; especially after the major energy crisis of the 1970s [1,2], wind energy continues to be the fastest growing power generating technology in the world [3].

Wind energy was the fastest growing energy technology in the 1990s, in terms of percentage of yearly growth of installed capacity per technology source. The growth of wind energy, however, is not evenly distributed around the world. By the end of 2001, the total operational wind power capacity worldwide was 23,270 MW. Of this, 70.3% was installed in Europe, followed by 19.1% in North America, 9.3% in Asia and the Pacific, 0.9% in the Middle East and Africa, and 0.4% in South and Central America [4].

Turkey is under the influence of different air masses. These air masses give rise to potential wind energy generation possibilities in different areas [5,6]. The Turkish State Meteorological Service (TSMS), founded in 1937, is the only legal organization in Turkey to provide all meteorological data and information.

Turkey has a considerably high level of renewable energy resources that can be a part of the total energy network of the country. Wind energy has received a lot of attention lately in Turkey as one of the most promising and economically feasible technologies for clean power generation, while the number of studies conducted on wave energy is relatively lower. Based on the values obtained from the latest Turkey Wind Atlas in 2002, Turkey's total theoretically available potential for wind power is found to be about 88,000 MW/year. Besides this, Turkey's wave power potential is estimated to be around 18,500 MW/year, with an average wave energy capacity of 140 billion kW h annually. These figures indicate that Turkey has considerable potential for generating electricity from wind and wave power. To date, four wind power plants have been installed, with a total capacity of 20.1 MW, while there are no wave energy plants installed in the country yet. Taking into account the present applications, it may be concluded that wind energy in Turkey is a promising alternative. As the public recognizes the projects, progress will continue [7].

Windmills (small wind turbines) have been utilized to pump water for years in the Aegean region. These turbine types consist of many blades, and they have very low efficiency in producing electricity. This study aims (i) to investigate the efficiency differences between three bladed glass reinforced plastics (GRP) rigid hubs, three bladed steel rigid hubs and 12 bladed steel rigid hubs experimentally, and (ii) to improve the performance of the small wind turbine system (SWTS) installed at Solar Energy Institute of Ege University (latitude 38.24° N, longitude 27.50° E), Izmir, Turkey. NACA 4415 (National Advisory Committee for Aeronautics) series blades are preferred to others in this experiment, because of the fact

that this profile has shown excellent properties for small wind turbine blades and the average power coefficients are higher than those of other blades.

In this study, first, blades are designed and manufactured according to the NACA 4415 profile type. Second, the performance parameters of the SWTSs are given. An experimental study is then presented. Finally, the results obtained from the present study are discussed.

2. System description

Fig. 1(a) and Fig. 1(b) illustrate the three bladed GRP rigid hub and 12 bladed rigid hub constructed SWTSs at the Solar Energy Institute in Ege University, Izmir, Turkey, while the main characteristics of the elements of the experimental set-up are given in Table 1. This system mainly consists of five parts: (i) rigid steel hub, (ii) blades, (iii) generator, (iv) conventional gear unit and (v) accumulators (batteries).

2.1. Blade type selection

In a horizontal axis wind turbine, useful energy is obtained from the wind using the lift and drag forces that affect the propeller blade. Therefore, selection of the airfoil form is very important for obtaining both energy and exergy efficiency from the SWTS.

The procedure of manufacturing the rotor blade followed in this paper consists of three stages.

2.1.1. Airfoil selection

The development of efficient (low-drag) airfoils was the subject of intense experimental investigations in the 1930s. These airfoils were standardized by the National Advisory Committee for Aeronautics (NACA, which is now NASA), and extensive lists of data on lift coefficients were reported.

The force a flowing fluid exerts on a body in the flow direction is called drag. The components of the pressure and wall shear forces in the direction normal to flow tend to move the body in that direction and are called lift. The aspect ratio is a measure of how narrow an airfoil is in the flow direction. The lift coefficient of wings, in general, increases while the drag coefficient decreases with increasing aspect ratio. This is because long narrow wings (large aspect ratio) have a shorter tip length and thus smaller tip losses and lower induced drag than short and wide wings of the same platform area [8–12].

The NACA 4415 airfoil is long and narrow and has a larger aspect ratio than the classical (short and wide wing) blade. Therefore, this airfoil was selected in this study.

2.1.2. Manufacture of the model

A full-scale exact geometry blade model was made from plaster and wood. This model is shown in Fig. 2. This method is useful for a designer to investigate some

(a)

(b)

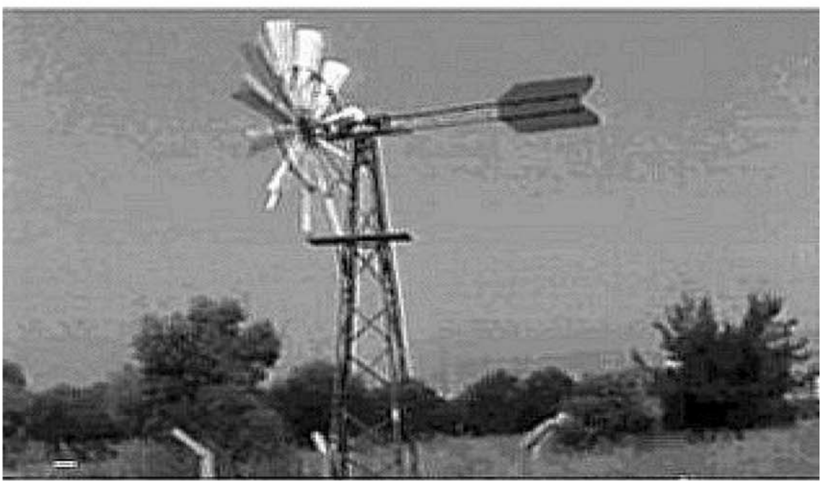

Fig. 1. A picture of (a) the three bladed (NACA 4415) (01/GEE/004 research project) and (b) the 12 bladed (classical—short wide wing) windmill system at the Solar Energy Institute of Ege University (98/GEE/004 research project).

Table 1
The main characteristics of the elements of the SWTS system studied

No.	Item	Blade Group I	Blade Group II	Blade Group III
1	Aerodynamic profile	Classical blade (short and wide wing)	NACA 4415	Classical blade (short and wide wing)
2	Manufacturing material of blade	Steel	GRP	Steel
3	Mold used to manufacture blade	Steel	GRP	Steel
4	Material ratio of blades	St37 (SAE 1015)	50% glass, 50% polyester	St37 (SAE 1015)
5	Average blade weight (g)	2100	1300	2100
6	Tensile strength (MPa)	240[a]	213.5[b]	240[a]
7	Power systems	DC	DC	DC
8	Inverter input voltage (V)	–	–	–
9	Inverter output voltage (V)	–	–	–
10	Generator average cos ψ	–	–	–
11	Batteries' charging voltage (V)	28	28	28
12	Batteries' charging current (A)	8	8	8
13	Charge controller disconnect voltage (V)	–	–	–
14	Height of hub (m)	6	6	6
15	Number of blades	12	3	3
16	Length of blade (m)	1.3	1.5	1.3
17	Cut-in velocity value (start-up wind speed) (m/s)	3.1	6.5	4.3
18	Cut-off velocity value (limiting wind speed) (m/s)	–	–	–
19	Theoretical maximum power factor value (–)	–	0.4531	–
20	Practical maximum power factor (–)	0.052	0.275	0.21
21	Produced maximum DC current value (A)	8	33	30
22	Power factor range	0.02–0.052	0.08–0.275	0.02–0.052
23	Momentum factor range	0.003–0.06	0.05–0.1928	0.08–0.157
24	Maximum alternative voltage value (V)	–	–	–
25	Frequency (Hz)	–	–	–
26	Maximum momentum factor value (–)	0.06	0.1928	0.1574
27	Roughness of blade surface	Clean	Clean	Clean
28	Theoretical profile tip loses efficiency (–)	–	0.912	–
29	Theoretical profile loses efficiency (–)	–	0.88	–
30	Optimum tip speed ratio, theoretical (–)	7	7	7
31	Optimum tip speed ratio, experimental (–)	0.867	1.45	1.29
32	Tip speed ratio range	0.78–0.89	1.3–1.711	1.34–1.39
33	Range of rpm of generator rotor	922–1210	1344–2722	1156–2332
34	Range of rpm of blades	37–48	54–108	46–93
35	Connection between generator and rotor/gear ratio	Gear/1:25	Gear/1:25	Gear/1:25
36	Generator type/capacity	DC alternator/ 250 W	DC alternator/ 250 W	DC alternator/ 250 W

Table 1 (*continued*)

No.	Item	Blade Group I	Blade Group II	Blade Group III
37	Accumulator (batteries)/unit	200 A h, 24 V/2	200 A h, 24 V/2	200 A h, 24 V/2
38	Brake system	–	–	–
39	Mechanical efficiency of system (–)	0.95	0.95	0.95
40	Generator efficiency (–)	0.98	0.98	0.98
41	Inverter and power group efficiency (–)	–	–	–
42	Gear system efficiency (–)	0.95	0.95	0.95
43	Estimated average decibel value (10 m from hub and average 7.5 m/s wind velocity)	75	45	60

[a] Theoretical maximum value.
[b] Experimental result.

parameters. The first step in making the model is to divide the blade length into four parts: the data are available for the outer 1.5 m part of the blade. This method is similar to Habali's methods [13,14].

2.1.3. *Manufacture of the mold and prototype blade*

The mold was made from GRP and consists of two parts: an upper half and a lower half. It is of great importance to locate the line where the two mold halves meet to avoid overlapping, which, because of blade twist, will result in a compli-

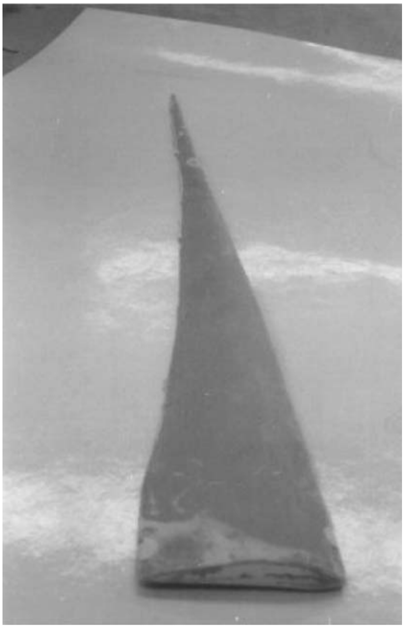

Fig. 2. A picture of the NACA 4415 blade model made of plaster and wood.

cated surface. However, the best guide is the chord line, which passes through the leading edge to the trailing edge of the airfoil section [14].

Every year, 1–2% of all rotor blades are struck by lightning in Denmark, which is one of the places in the world least affected by lighting. On large modern wind turbines, rotor blades count among the most expensive single components. Many types of damage can be repaired, but this often requires complete blade replacement. The extent of the damage depends on the blade type, but the risk of being struck by lightning is irrespective of blade material—wood or glass fiber—and whether the blade contains electricity-conducting parts. Repair of damage caused by lightning can be very expensive, both in the mounting and dismantling of tips or whole blades and in operating loss while the damage is being repaired [15].

2.2. Experimental methodology and measurement system

There are three basic methods of testing wind turbine rotors, each method having its own advantages and disadvantages. Wind tunnel testing, the mainstay of the aircraft industry, has been of limited value in wind turbine rotor development, although it is useful for obtaining basic two dimensional airfoil lift and drag data. While tests in a facility such as the NASA Ames research center's 40-ft $\times$ 80-ft wind tunnel could provide useful data, financial limits have restricted the size of tunnels that the wind industry can afford.

Tow testing, whereby the wind turbine is pulled or pushed through static air, can relieve the scaling and blockage problems of wind tunnels, but the rotor size is limited. The tow testing of a 15-m diameter wind turbine, for example, would be a formidable task. Tow testing also shares with wind tunnel testing the problem of failing to subject the wind turbine to the unsteady nature of wind [16].

Field testing presents the proper wind environment, but it brings new challenges in measuring and recording test data; the method which was used in this case greatly smoothes the resulting graph of the power curve.

Performance data from the wind turbine are stored. Output power and wind speed are sampled over periods of time and average values of wind for each period are stored in wind speed.

3. Theoretical analysis

The procedure of theoretical analysis of the SWTSs followed in this paper consists of two stages.

3.1. Performance parameters of the SWTS

Designing wind turbines to achieve satisfactory levels of performance and durability starts with knowledge of the aerodynamic forces acting at the critical interface between wind and machine.

The efficiency of a wind turbine is usually characterized by its power coefficient as given below. Maximum values of C_p can be 0.5926 according to Betz criteria.

$$C_p = \frac{I \cdot V}{\eta_{\text{mechanic}} \eta_{\text{alternator}} 0.5 \rho \pi R^2 V_r^3} = \frac{P_a}{P} \tag{1}$$

where C_p is the power performance of the wind turbine. The power coefficient is given by Eq. (1). In this study, electrical equipment and mechanical equipment (especially gear) losses were assumed to be $\eta_{\text{alternator}} = 0.98$ and $\eta_{\text{mechanic}} = 0.95$, respectively.

The aerodynamic lift coefficient (C_L), aerodynamic drag coefficient (C_D) and attack angle values were taken as 1.2°, 0.019°, and 10°, respectively [12].

The power performance of a wind turbine can be expressed using fixed angular velocity. This parameter is defined as

$$C_M = \frac{C_p}{\lambda} \tag{2}$$

Wind turbines have various C_p values depending on the wind velocity. Therefore, their efficiency is best represented by a C_p–λ curve. The tip speed ratio, λ, is given by

$$\lambda = \frac{\omega R}{V_r} \tag{3}$$

where λ is tip speed ratio, R is maximum rotor radius (m), ω is rotor speed (rad/s) and V_r is wind velocity (m/s). Flowing wind has the same properties as stagnant air except that it possesses a velocity and thus some kinetic energy. This air reaches the dead state when it is brought to a complete stop. Therefore, the availability of wind is simply the kinetic energy it possesses:

$$\text{Availability} = ke_1 = \frac{V_r^2}{2} \tag{4}$$

To determine the available power, we need to know the amount of air passing through the rotor of the windmill per unit time, the mass flow rate. Assuming standard atmospheric conditions (25 °C, 101 kPa) in this study, the density of air is 1.18 kg/m^3, and its mass flow rate is

$$\dot{m} = \rho A V_r = \rho \pi R^2 V_r \tag{5}$$

Thus,

$$\text{Available power} = P = (\dot{m} ke_1) \tag{6}$$

This is the maximum power available to the windmill. Most windmills in operation today harness about 20–40% of the kinetic energy of the wind [17].

Average values of the performance parameters (conversion efficiencies, available power, actual SWTS power, spin numbers of blade groups, momentum factors) of the SWTSs are obtained by using Eqs. (1)–(6), as summarized in Table 2.

Table 2
Measured and calculated average values of performance parameters of the SWTS for Blade Groups I, Blade Group II and Blade Group III

Twelve bladed classical SWTS (Blade Group I)									Three bladed modern (NACA 4415) SWTS (Blade Group II)									Three bladed classical (short and wide wing) (SWTS Blade Group III)								
V_r	n	λ	C_p	c_m	$\dot{m}$	ke_1	P (W)	P_a (W)	V_r	n	λ	C_p	C_m	$\dot{m}$	ke_1	P (W)	P_a (W)	V_r	n	λ	C_p	C_m	$\dot{m}$	ke_1	P (W)	P_a (W)
6.5	922	0.891	0.002	0.003	40.7	21.13	859.9	1.72	6.5	1344	1.3	0.16	0.12	54.22	21.13	1146	183.4	5.4	1156	1.345	0.211	0.157	33.81	14.58	492.9	104
7.3	1000	0.860	0.031	0.036	45.71	26.65	1218	37.76	6.8	1429	1.32	0.17	0.128	56.72	23.12	1311	222.8	6.0	1220	1.277	0.191	0.149	37.57	18	676.3	129.2
7.5	1050	0.879	0.045	0.052	46.96	28.13	1321	59.95	7.2	1558	1.36	0.21	0.154	60.05	25.92	1557	326.9	6.9	1365	1.242	0.176	0.141	43.2	23.81	1029	181
7.7	1071	0.873	0.048	0.055	48.21	29.65	1429	68.59	7.6	1693	1.4	0.27	0.192	63.39	28.88	1831	494.3	7.5	1550	1.298	0.182	0.140	46.96	28.13	1321	240.4
8.0	1105	0.867	0.052	0.060	50.09	32	1603	83.36	7.9	1823	1.45	0.275	0.189	65.89	31.2	2056	565.4	8.3	1643	1.243	0.149	0.120	51.98	34.45	1788	266.4
8.5	1115	0.824	0.045	0.055	53.22	36.13	1923	86.5	8.1	1934	1.5	0.25	0.166	67.56	32.8	2216	554	8.4	1733	1.296	0.157	0.121	52.59	35.28	1855	291.3
8.6	1130	0.825	0.047	0.057	53.85	36.98	1991	93.6	8.3	2060	1.56	0.18	0.115	69.2	34.4	2380	428.4	9.0	1912	1.334	0.147	0.110	56.35	40.5	2282	335.4
9.0	1170	0.816	0.048	0.058	56.35	40.5	2282	109.5	9.0	2306	1.61	0.12	0.074	75.06	40.5	3040	364.8	9.5	2012	1.330	0.134	0.100	59.48	45.13	2684	360
9.5	1180	0.780	0.042	0.054	59.48	45.13	2684	112.7	9.5	2495	1.65	0.09	0.054	79.24	45.13	3576	321.8	10.0	2125	1.335	0.122	0.092	62.62	50	3131	382
9.7	1210	0.783	0.043	0.056	60.74	47.04	2857	122.8	10.0	2722	1.71	0.088	0.051	83.41	50	4171	367	10.5	2332	1.395	0.117	0.084	65.75	55.13	3625	424.1

3.2. Typical calculation of gross annual wind loads and energy production (output)

One of the significant measures of the cost-effectiveness of a wind turbine is its production of energy. In the design and analysis of wind turbines, the annual energy output is calculated. Calculation of annual energy output requires knowledge of the wind speed frequency distribution and the system power output of the turbine as a function of wind speed. Furthermore, every prediction of annual energy output is specific, depending on the local wind flow patterns and turbulence, and the local air density [16]. Wind speed data collection is done at intervals of 1 s and hourly average values are also recorded. All measurements were obtained at an anemometer height of 15 above ground level [18]. The wind speed measurement system was installed in May 1994 and the measurements were carried out up to the middle of the year 2000 [19]. Table 3 illustrates the design performance data for Blade Group I, Blade Group II and Blade Group III and shows, over a five year period from 1995 to 1999, the cumulative times for each wind speed range (for more details, see [19]). As can be seen in Table 3, annual energy output is calculated according to whole year (over a five year period from 1995 to 1999) wind speed data.

Table 3
Typical calculation and theoretical results of whole-year (from 1995 to 1999) average energy production (output for blade groups)

Wind speed (m/s)	Cumulative time, Δt_1 (1995–1999) (h/whole year)	Actual SWTS power (kW)			Theoretical energy output (kW h/whole year)		
		Blade Group I (P_{a1})	Blade Group II (P_{a2})	Blade Group III (P_{a3})	Blade Group I $(P_{a1})\cdot(\Delta t_1)$	Blade Group II $(P_{a2})\cdot(\Delta t_1)$	Blade Group III $(P_{a3})\cdot(\Delta t_1)$
0–1	8129	0	0	0	0	0	0
1–2	7897	0	0	0	0	0	0
2–3	7641	0	0	0	0	0	0
3–4	7957	Cut-in 3.1 m/s	0	0	Cut-in 3.1 m/s	0	0
4–5	6610	Negligible	0	Cut-in 4.3 m/s	Negligible	0	Cut-in 4.3 m/s
5–6	3569	Negligible	0	Negligible	Negligible	0	Negligible
6–7	1368	Negligible	Cut-in 6.5 m/s	Negligible	Negligible	Cut-in 6.5 m/s	Negligible
7–8	432	0.086	0.458	0.35	37.152	197.856	151.2
8–9	152	0.126	0.667	0.509	19.152	101.384	77.368
9–10	44	0.176	0.931	0.71	7.744	40.964	31.24
10–11	23	0.237	1.258	0.96	5.451	28.934	22.08
11–12	2	0.312	1.6525	1.26	0.624	3.305	2.52
12–13	0	0	0	0	0	0	0
13–14	0	0	0	0	0	0	0
14–15	0	0	0	0	0	0	0
Total	43,824				70.123	372.443	284.408

4. Results and conclusions

Experimental results [20–21] can be seen clearly in Tables 2 and 3 and Fig. 3. Average values of measured and calculated performance parameters (C_P, C_M, etc.) of the SWTS for Blade Group I, Blade Group II and Blade Group III are given in Table 2, while typical calculation and theoretical results of whole year (1995–1999) average energy production are given in Table 3. According to Tables 2 and 3, the blade test involved two different models: the NACA 4415 profile and the classical blade (short wide wing). Although Blade Group II has very high cut-in velocity (6.5 m/s) compared to other blade groups, the test result showed that Blade Group II of GRP (NACA 4415) was more efficient than Blade Group I and Blade Group III (short wide wing) in the SWTS. It means that both energy and exergy [22] efficiency can be increased by changing just the blade design of the small wind turbine; this provides more annual energy production from the turbine and the manufacturer's power curve can be greatly improved. Fig. 3 shows that (a) the theoretical power curve of the three bladed windmill—NACA 4415 profile, (b) the

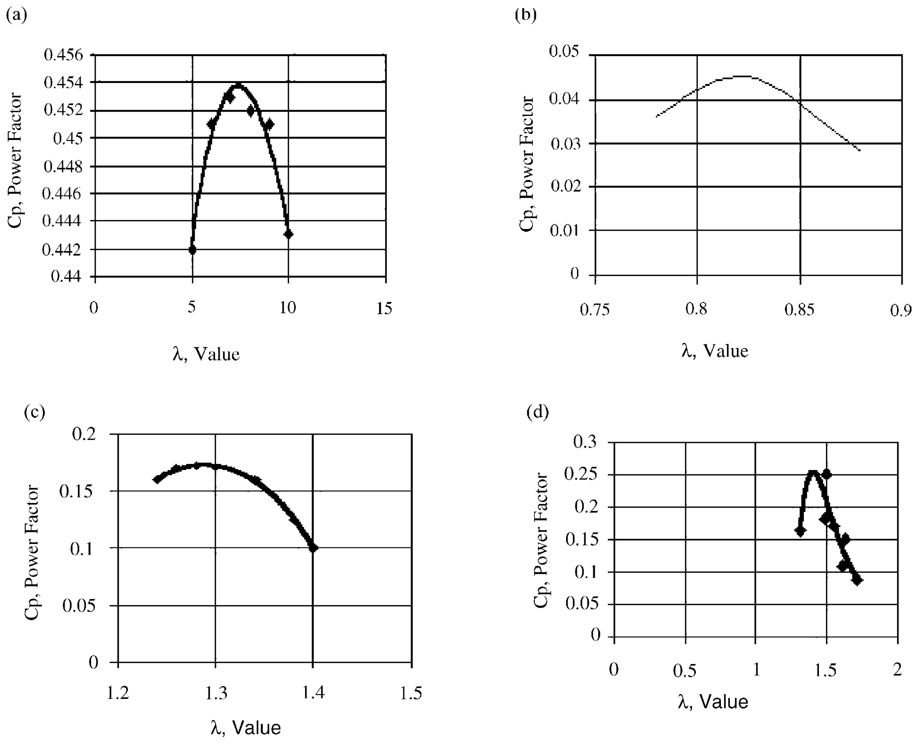

Fig. 3. Comparisons of actual power curves and power coefficients for the SWTS at the Solar Energy Institute in Izmir. (a) Theoretical power curve of three bladed windmill—NACA 4415 profile. (b) Power curve of 12 bladed windmill—short wide wing. (c) Power curve of three bladed windmill—short wide wing. (d) Power curve of three bladed windmill—NACA 4415 profile.

power curve of the 12 bladed windmill—short wide wing, (c) the power curve of three bladed windmill—short wide wing, (d) and the power curve of three bladed windmill—NACA 4415 profile. The experimental results did not reach the maximum theoretical power factor of the three bladed windmill (NACA 4415 profile) of 0.45 in this study. On the other hand, the SWTS energy and exergy performance and safety can be increased in this study and other applications in the Aegean region, if the suggestions of producing methodologies of windmill systems given below are followed:

- Blade:
  - A steel mold can be used to produce a smooth surface.
  - A long and narrow airfoil can be selected having larger aspect ratio than the classical (short and wide wing) blade.
  - Blades can be made of epoxy–carbon fiber or GRP.
  - Steel blades should not be used due to their weight and corrodibility.
  - Lighting protection can be provided for GRP epoxy–carbon fiber blades.
  - The rotor blades can be improved, but there are many profiles that might be used, and in addition, there is no requirement that the same profile should be used throughout the blade length. The power factor value can be increased, but investment and producing cost of blades are quite high for a small windmill.
- Location:
  - Picking the initial location can be done using empirical guidelines formulated for evaluating the effects of local topography and roughness elements affecting the wind, including the effects of tress and buildings [16,23–26], which can reduce system performance and affect experimental measurement. Therefore, the height of hub should be higher than that of the buildings and tress. Otherwise, vortex formation can effect system efficiency.
- Wind:
  - Local values of wind velocity should be 3 m/s or higher, and the wind should be steady, to produce electricity effectively.
- Mean gear system:
  - This system should not be used in SWTSs due to high friction.
  - Direct fixed connection can be used between generator and blades rotors. This can increase C_p values due to lower friction.
- Brake system:
  - Brake systems are not sufficient or are absent in windmill systems in Turkey, so this system need to be improved.

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References

[1] Sen Z, Sahin A. Regional assessment of wind power in western Turkey by the cumulative semivariogram method. Renewable Energy 1997;12(2):169–77.
[2] Sayigh A. Renewable energy—the way forward. Applied Energy 1999;64:15–30.
[3] Ozgener O, Hepbasli A. Current status and future directions of wind energy applications in Turkey. Energy Source 2002;24:1117–29.
[4] Ackermann T, Soder L. An overview of wind energy-status 2002. Renewable and Sustainable Energy Reviews 2002;6:67–128.
[5] Durak M, Sen Z. Wind power potential in Turkey and Akhisar case study. Renewable Energy 2002;25:463–72.
[6] Oztopal A, Sahin AD, Akgun N, Sen Z. On the regional wind energy potential of Turkey. Energy 2000;25:189–200.
[7] Hepbasli A, Ozgener O. A review on the development of wind energy in Turkey. Renew Sustain Energy Rev 2004:8;257–276.
[8] Cengel YA, Turner RH. Fundamentals of thermal-fluid sciences. McGraw Hill; 2001.
[9] Abbott IH. The drag of two streamline bodies as affected by protuberances and appendages. NACA Report 451.1932.
[10] Abbott IH, Von Doenhoff AE, Stivers LS. Summary of airfoil data. NACA Report 824, Langley Field, VA, 1945.
[11] Abbott IH, Von Doenhoff AE. Theory of wing sections, including a summary of airfoil data. New York: Dover; 1959.
[12] Hau E. Windkraftanlagen. Berlin: Springer Verlag; 1996.
[13] Habali SM, Saleh IA. Local design, testing and manufacturing of small mixed airfoil wind turbine blades of glass fiber reinforced plastics part I. Design of the blade and root. Energy Conversion and Management 2000;41:249–80.
[14] Habali SM, Saleh IA. Local design, testing and manufacturing of small mixed airfoil wind turbine blades of glass fiber reinforced plastics part II: Manufacturing of the blade and rotor. Energy Conversion and Management 2000;41:281–98.
[15] Available from: http://www.lm.dk.
[16] Spera DA. Wind turbine technology fundamental concepts of wind turbine engineering, vol. 430. New York: ASME Press; 1994, p. 283–98.
[17] Cengel YA, Boles MA. Thermodynamics: an engineering approach. 1994.
[18] Colak M, Gunerhan H, Gunerhan GG. Investigation on the relation between solar energy system and wind and the other meteorological conditions. Ege University Research Foundation project no. 93/GEE/007, Izmir, Turkey, 1999.
[19] Ulgen K, Hepbasli A. Determination of Weibull parameters for wind energy analysis of Izmir, Turkey. International Journal of Energy Research 2002;26:495–506.
[20] Ozdamar A, Ulgen K, Buyuktuna V, Ozgener O. A research of power and momentum factor analysis of wind roses on Aegean Region. Research project 98/GEE/003, Ege University Solar Energy Institute, Bornova, Izmir, Turkey, 2001 [in Turkish].
[21] Ozgener O. M.Sc. Thesis. Investigation of blade of wind rose and power gain. Mechanical Engineering Science Branch, Graduate School of Natural and Applied Sciences, Ege University, Izmir, Turkey, 2002, p. 92 (in Turkish).
[22] Koroneos C, Spachos T, Moussiopoulos N. Exergy analysis of renewable energy sources. Renewable Energy 2003;28:295–310.
[23] Frost W, Nowak DK. Guidelines for siting wind turbine generators relative to small scale, two dimensional terrain features. Report RLO/2443-77/1, Battelle Pacific Northwest Laboratory, Richland, Washington, 1979.
[24] Frost W, Shieh CF. Wind turbine generator siting guidelines relative to terrain features. Final report, DOE Contract Ac06076ET20242, FWG Associates, Inc., Tullahoma, Tennessee, 1980.
[25] Wegley HL, Ramsdell JV, Orgill MM, Drake RL. A siting handbook for small wind energy conversion systems, PNL-2521, Rev. 1. Richland (WA): Battelle Pacific Northwest Laboratory; 1980.

[26] Ozgener O, Ozdamar A. Improving the power factor of a wind rose with optimum blade design. Ege University Research Fund Project, Number: 2001/GEE/004, Izmir, 2003, p. 34.